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# PHYSICAL SELENOGRAPHY

V. V. Shevchenko



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# PHYSICAL SELENOGRAPHY

V. V. Shevchenko*

ABSTRACT. Physical selenography is discussed in light of the most recent observations (Lunokhod-I, Apollo, observations from Earth). The gas distribution, surface composition, and other physical features of the Moon are discussed.

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The outstanding achievements of space science and technology, including /37** the successful flight of the "Lunar-16" unmanned probe, which brought back to the Earth samples of the lunar soil obtained from the Sea of Fertility, and the unique studies done in the Sea of Rains by Lunokhod-1, which was carried to the Moon aboard the "Lunar-17" unmanned probe, again called attention to the problems involved in the exploration of the natural satellite of the Earth. The Earth's nearest companion conceals diverse information about the origin and formation of planets in the solar system and about the existence of planetary matter under conditions different from those on the Earth. As shown by research

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**Numbers in the margin indicate the pagination in the original foreign text.

done in the last few years, the best result is obtained by combining the classical methods of planetary astrophysics with the newest achievements of space science and technology. The astrophysical data obtained by Earth-based observers or transmitted back to the Earth by unmanned probes have been enriched with new, more specific information due to the data on the mineralogical, physico-mathematical, and structural features of the lunar soil. This information was obtained using devices which were in direct contact with the lunar surface. Problems involved in a comprehensive exploration of the lunar surface are discussed in the article below.

The terrestrial environment, surrounding us always and everywhere, has been an object of study for physical geography for many centuries. Physical geography has defined the concept of the planetary "boundary layer"(1) as a landscape zone and has pointed out the dialectical unity of the systems included in the landscape zone, and the mutual dependence and interconnection of all its components.

This methodologically important principle retains its importance also when exploring other planets and satellites that posess a "boundary layer". The "boundary layer" of the Moon with all its features can be truly classified as a landscape zone. A study of the various properties of the lunar landscape zone in their totality requires a complex method of investigation. This method probably deserves to be called physical selenography, by analogy with the name of a science dealing with the terrestrial environment.

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(1) In the transition from a solid planetary body to outer space, a certain "boundary layer" arises whose composition and nature are determined by the parameters of a given celestial body and the character of its interaction with interplanetary space. This layer is thin compared with the dimensions of the planet and carries traces of both the evolution of the interior and the influence of the external cosmic factors. Depending on the mass of the celestial body, the "boundary layer" may possess a more or less complicated structure and a greater or lesser number of the states of the matter. All the properties of the "boundary layer" produce the concept of a planetary environment.

A characteristic feature of physical selenography is its "astrophysical nature". /38

The total area of the Moon is 38 million $km^2$, but only a $1/10^{10}$ fraction of it can be described in terms of the results obtained from direct contact with the surface. The parameters of the remaining area are determined by studying the direct or reflected electromagnetic radiation of the Moon, i.e., by astrophysical methods with the help of the equipment on space stations or terrestrial observatories.

Astrophysical research has thus far established a number of fundamental relationships applicable to the properties of the lunar mantle and, on the average, valid for the entire surface of the Moon. These results became a starting point for research in the area of physical selenography.

Physical selenography, possibly for still a long time to come, will remain one of the few lunar sciences that employ astrophysical methods of investigation. This puts it in contrast with, for example, selenochemistry, in which the fundamental information can be obtained only through a direct contact with the lunar surface.

## LUNAR LANDSCAPE ZONE

The lunar landscape zone is much simpler than its terrestrial equivalent. Only one state of matter exists in it. Liquids are not found on the Moon, and a gaseous envelope is practically absent. Thus the structure of the lunar landscape zone will be as shown in Fig. 1.

Under terrestrial conditions, a fairly dense atmosphere insulates the geographical zone from outer space to a certain extent. Under lunar conditions, a solid surface is exposed to all processes that occur in outer space, which are manifested on the Moon in one way or another. Consequently, the external factors are an important component of the lunar environment and comprise the lunar landscape zone from above. The processes taking place in the lunar lithosphere play an organizing role (or played in the past) of no lesser importance. Our knowledge is, unfortunately, most complete only with respect to the external factors influencing the lunar surface.

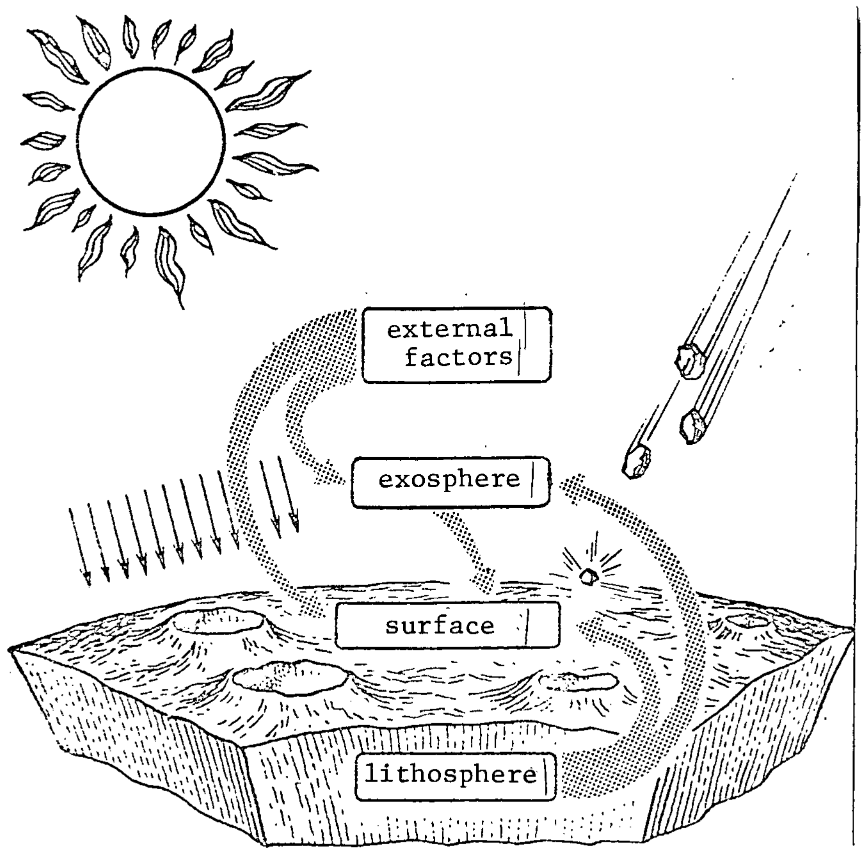


Figure 1.
A sketch of the interaction among various components of the landscape zone of the moon. The landscape zone formed due to the following external factors: solar radiation, impact of meteors, etc. Below, a similar effect is caused by endogenic processes. Both of these components determine the nature of both the lunar surface and the lunar exosphere.

Due to the absence of an atmosphere, the lunar mantle is exposed to all types of radiation. The solar electromagnetic radiation is of course of highest intensity. As we know, its maximum is in the visible portion of the spectrum. A greater part, 99% of the solar energy, is radiated within the wavelength range from 0.3 to 4.0 μ. Since the "windows" of the Earth's atmosphere lie approximately in the same region, it is rather simple to imagine the effect of radiation on the lunar surface, excluding such phenomena as absorption, scattering of light, etc., which are due to the Earth's gas envelope.

The lunar surface is also under the influence of solar and galactic corpuscular radiation. Some calculations indicate that within a period of about 4.5 billion years, such influences could alter from 1 to 2 g of the surface layer for each $cm^2$ of the surface.

The most palpable external factor responsible for the formation of the lunar landscape zone is the impact of meteors. Terrestrial observations, as well as the results of meteor monitoring from on board spacecraft, permit us to estimate the total mass falling on the lunar surface. Taking into account all possible sources — from dust particles with a mass on the order of $10^{-14}$ g to asteroids and heads of comets whose mass reaches $10^{18}$ g — the total flux is about $4 \times 10^{-14}$ g $cm^{-2}$ $sec^{-1}$. An intuitive feeling for this quantity is obtained by calculating the width of the deposited layer (disregarding its scattering from the surface). If the density is 1 g $cm^{-3}$, the thickness of the layer will be about 50 m after 4 billion years. /39

Recent studies, in particular a detailed chemical analysis of the lunar samples[(2)], have shown that the Moon has undergone a considerable evolution. The absence of volatile elements and the high concentration (as compared with the average in space) of titanium and zirconium indicate that the Moon was once heated to high temperatures. The study of the samples showed traces of chemical differentiation which took place approximately 4.6 billion years ago. This process should have led to the formation of the lunar crust. Calculations of the possible thickness of the lunar crust yield a value of about 100 km, assuming total differentiation, and about 10-15 km assuming the completion of only certain stages of this process. According to the interpretation of the

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(2) See "Priroda", 1969, No. 12, pp. 50-59 and 1970, No. 10, pp. 46-54.

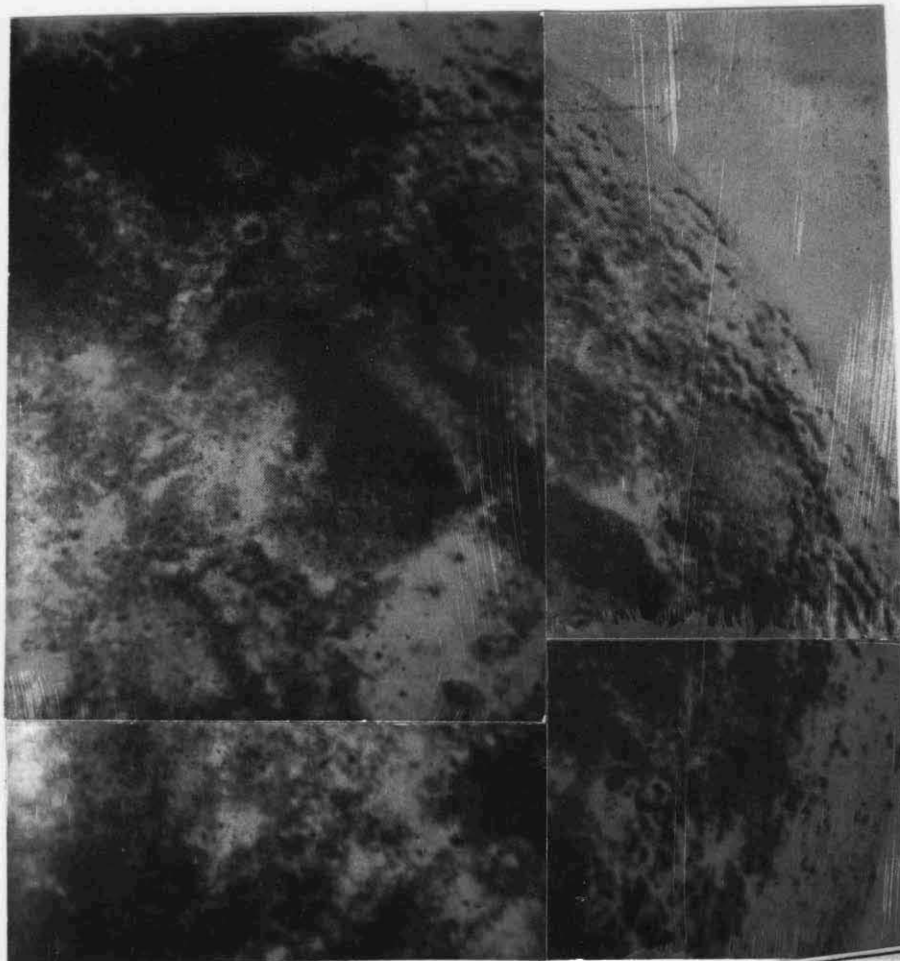



Figure 2.

Light-separated photograph of a region including the Sea of Serenity and the Sea of Tranquility. The combined image was put together by combining the negative of a picture obtained in the far red region of the spectrum, and a positive of a picture obtained in the ultraviolet portion of the spectrum. This technique is used to increase the contrast between portions of different color. A darker tint corresponds to a greater "reddening" of the surface.

seismic experiment on the Moon, the upper mantle comprises about 20 km. Finally the lower boundary of the lithosphere can be obtained from the depth at which masscons are found[3].

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[3] See "Priroda", 1970, No. 3, pp. 84-87.

According to the present-day model of the moon, maria are regions flooded by the lava from underneath the crust. Apparently, it is clear that there is a relationship between masscons and the formation of a majority of maria, which occurred at a great depth. The data obtained from the lunar satellites permit us to assume that the depth of perturbing points in masscons is from 25 to 125 km. The typical depth at which masscons can be found is estimated to be on the order of 50 km. Since at the present time many processes occurring in the lunar lithosphere are unknown, it is difficult to decide where to place the lower boundary of the landscape zone.

The problem of the existence of a lunar atmosphere was studied thoroughly many times. According to optical studies, the density of the hypothetical lunar atmosphere is about $10^{-10}$—$10^{-13}$ of the density of the Earth's atmosphere, which approximately corresponds to the best vacuum that can be obtained under laboratory conditions. This means that the thickness of the atmosphere is less than mean free path of the particles in it, so that the atoms and molecules move along ballistic trajectories similar to a thrown stone, and do not collide with one another. Either they fall on the moon (collide with its surface and either bounce from it or adhere to it), or, if their velocity is greater than the second cosmic velocity* for the Moon, they escape into interplanetary space. Consequently, a certain region above the surface of the Moon can be justifiably called its exosphere by analogy with the upper layer of the Earth's atmosphere from which gas molecules can escape into outer space.

The gas residues in the lunar exosphere may be of various origin. One of such sources is the degassification of the lunar interior. In the past, this process was probably very intense. However, many researchers think that the primordial composition of the lunar exosphere has not been preserved. The known observations of the brief glow in various parts of the Moon (which can be /40 interpreted as phenomena that accompany the escape of gases) may possibly indicate that degassification supplying the exosphere occurs also today.

*Translator's Note: This is the minimum initial velocity which, if imparted to a body near the surface of a celestial body, enables this body to escape from the gravitational pull of the celestial body.

Since the density of gases in the lunar exosphere is extremely small, even a source such as the capture of solar wind particles may turn out to be important. We have no doubts that a considerable fraction is contributed by the products of evaporization during explosions accompanying the fall of meteorites. In recent times there has also appeared another source of artificial origin which can best be called a source of contamination. When spacecraft land on the Moon, its exosphere receives a fair amount of extraneous substances. For example, the landing gear of an Apollo spacecraft causes in one way or another about five tons of gases to be added to the space around the Moon. Taking into account the negligible mass of the gas envelope around the Moon, which in some estimates does not exceed 100 tons, this type of artificial addition to the exosphere is a serious threat to the existence of this component of the lunar landscape zone in its natural state.

The lunar surface is highly homogeneous in many of its characteristics. The relief forms are also relatively homogeneous. On a global scale, we can distinguish between two types of landscape: continents and marias. A more detailed and comprehensive study of the medium- and large-scale photographs of the surface will enable us to establish a more detailed characterization with some intermediate forms.

During its entire history, the lunar surface has undergone changes under the influence of the specific components of the lunar landscape zone. The "primordial" landscape has been changing for 4.5 billion years under the influence of external factors. In the regions of present-day maria, over a portion of the lunar surface, we see an unquestionable manifestation of the internal processes in the crust, which approximately 1- 1.5 billion years after formation of the Moon gave rise to a landscape of the maria type. In turn, this younger surface was again subject to the action of external factors.

The lunar surface changes its optical properties and structure under the influence of the various types of radiation. The thin upper layer of the crust, on the order of 0.5 -1.0 mm in thickness, is frequently illuminated. In this case the albedo varies by 2-3%. The enormous 24-hour differences

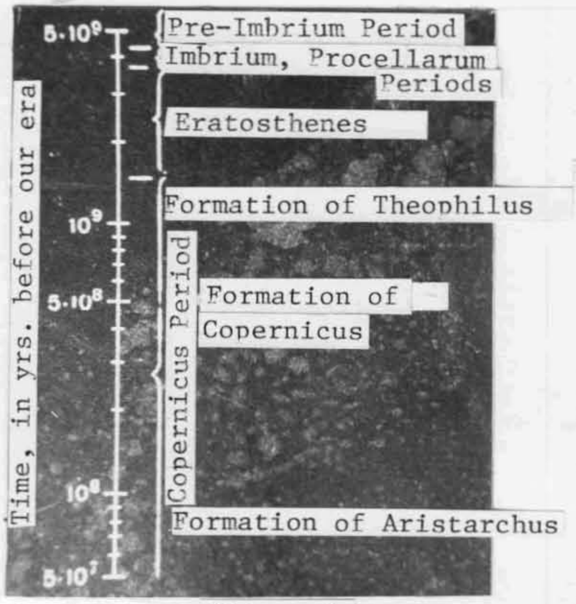


Figure 3.

Approximate absolute time scale for the development of the Moon. The Imbrium and Procellarum periods encompass the formation of the lunar maria. The Eratosthenes and Copernicus encompass the appearance of major post-maria craters.

in the surface temperature, reaching about 270°, should apparently result in the destruction of the surface layer. This is confirmed indirectly by seismic experiments. The readings of a seismometer placed on the lunar surface indicate that there is a correlation between the maximum frequency of the shocks and the hottest period of the lunar day. Due to the small heat conductivity, the depth of destruction is probably very small, since the temperature changes probably occur only to within the depth of no more than 1 m.

The greatest depth of penetration is characteristic of the processes caused by the impact of meteorites. The lunar samples investigated carry traces of bombardment with tiny supersonic particles, in the form of indentations about 10 μ in diameter. The upper limit of the typical size of impact craters is as yet difficult to determine, but it can probably reach tens of kilometers. Thus, small-size particles are capable of changing the fine structure of the crust on a scale in which the effects of radiation and the larger effects of thermal destruction are manifested. The fall of large-mass, high-velocity bodies gives rise to craters whose diameter ranges from hundreds of kilometers to several centimeters. During a period of about 4 billion years, this type of processes should have resulted in the "plowing over" of the outer layer up to a depth ranging from 10 to 500 m, resulting in complete destruction of all old craters of diameters up to 30 m.

As we know, the impact crater is not the only effect of an explosion. If the falling body has an average velocity of 15 km/sec the mass ejected from the crater is 100 times greater than the meteorite causing the explosion. As a result, the creation of a crater on the Moon is accompanied by a no less intensive formation of a debris field, i.e., rocks lying on the inner slopes of the crater and in its neighborhood. As shown by direct measurements, the albedo of the rocks may be 20 — 25%. With the average albedo of the maria surface being 6 — 7% and that of continents being 12 — 13%, the rocks and the segregations of rocks have higher brightness. This may be the reason for the great brightness of the inner slopes of young craters and the surrounding halos and rays. The brightness of the major ray systems, observed from the Earth, may be explained by the higher concentration of secondary craters and rocks in the intercrater space. In time, the rocks are destroyed by erosion and disappear. The inner slopes of the old craters get darker and the ray systems vanish.

The variation of the optical characteristics of the upper layer under the influence of the incident radiation, higher concentration of rocks and craterholes (at a resolution which does not reveal each of the objects separately), can be registered as a variation in the albedo. In addition, different degrees of soil roughness, rock and crater accumulations appear as variations in the brightness of a given region under different conditions of illumination, i.e., they are, on the average, described by the photometric function of the region. In spite of the fact that we are dealing with the optical properties of the uppermost layer of the lunar soil, their changes when passing from one region to another serve as an important parameter. The loose regolithic layer, for example, and the outcrops of bedrock will react differently to the isotropic influence of external factors, and this is how they reveal their presence. /41

Segregations of rocks are, in particular, revealed when studying the thermal properties of the lunar surface. An analysis of the eclipse and night temperatures of various lunar regions reveals the existence of a large number of anomalous regions. The characteristic features of these regions are that on the dark side of the Moon (this is most sharply revealed during an eclipse) they cool off more slowly then their surroundings and also heat up more slowly. This can be explained as being due to a difference in the density and heat conductivity. On the other hand, certain theoretical calculations explain the

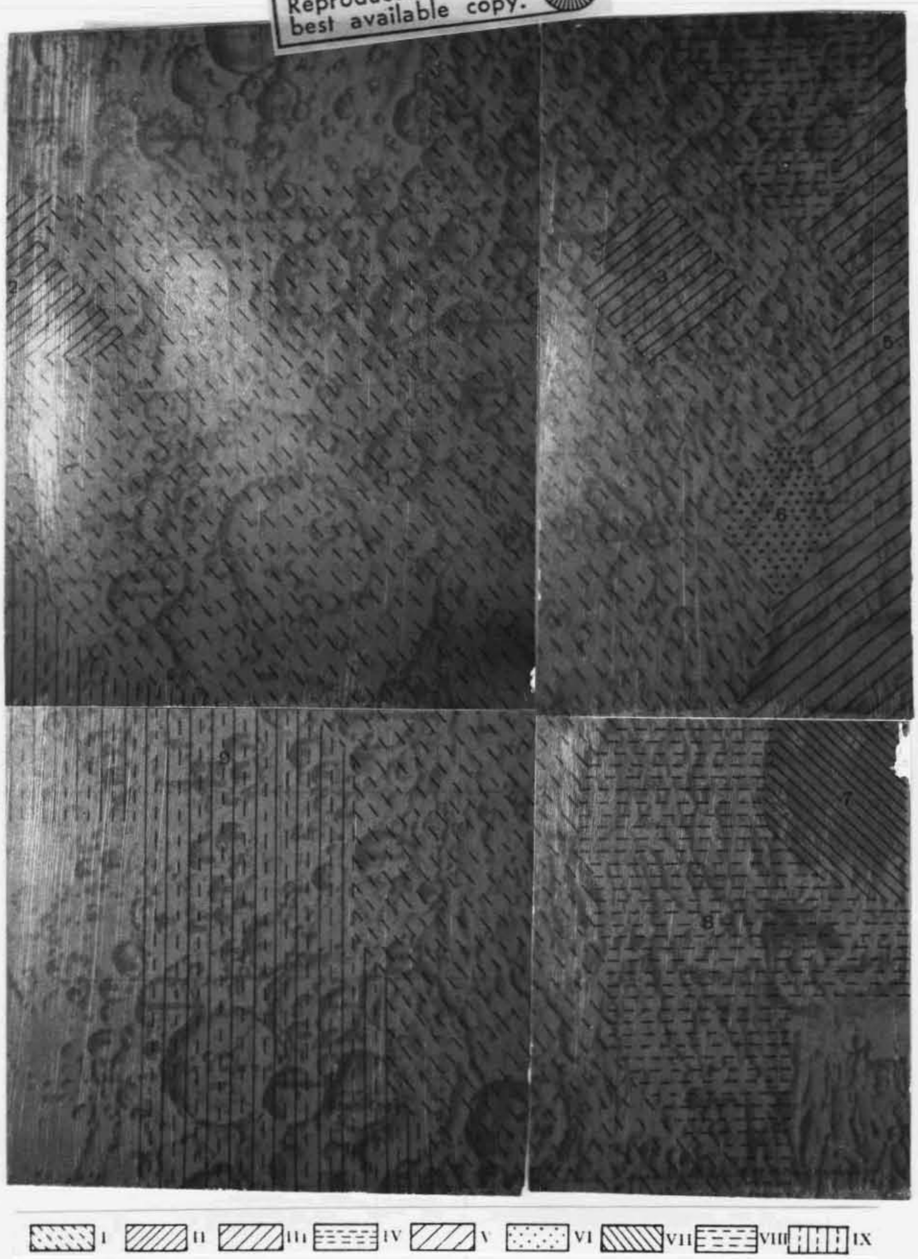


Figure 4.

Photometric map of a portion of the eastern sector of the far side of the Moon. I-IX represent types of photometric relief. The photometrically prominent regions have a large number of fissures in the neighborhood of the Eastern Sea (region 5, type III of the "photometric relief" and region 8, type IV of the "photometric relief"). The "photometric relief" of type V is interesting. High albedo, low relative porosity and slope angles, indicating a preponderance of negative relief forms, point to a high concentration of rocks within region 9. This conclusion is not contradicted by the morphological feature of the region. As compared with other regions (regions 1,8) in this area, there is a higher crater density per unit area. The latter circumstance usually indicates a greater concentration of rocks.

above effect as being caused by nonuniformities in the centimeter range. Radar measurements in the centimeter range show that regions with a more uneven terrain coincide with regions exhibiting thermal anomalies.

All this leads us to the conclusion that rock segregations exist in the anomalous regions, and that the predominant size of the rocks is in the centimeter range, and the density, as shown by the data from automatic stations, is higher than the density of the substrate layer. Certain indications as to the existence of a correlation between the intensity of rocks and the location of thermal anomalies were also obtained from studying large-scale photographs.

Thus, it turns out that certain reflective and thermal properties are determined by the structure of the soil and the characteristic features of the relief.

The formative role of the processes occurring in the lithosphere is most clearly expressed in the formation of the lunar maria. There are two points of view with respect to the causes of the subcrust lava outflow on to the surface. According to one of them, the internal processes were of independent importance, and were triggered by certain global influences: tidal forces, subsidence on the scale of the entire lunar sphere, etc. The second version relegates the internal processes to a passive role of secondary phenomena, when the lava outflows were due to the impact of large mass (planetisimals). Individual lava flows are clearly visible against the maria-type landscape in a number of cases. The dynamics of lava fields can be even more clearly seen in colorimetric studies. The color contrasts of the lunar soil are very small in the visible part of the spectrum. The surface mostly has the color of neutral gray with a brown tint. However, the intensity of light reflection in the ultraviolet and in the red or infrared portion of the spectrum shows significant color differences (Fig. 2). For example, in the Sea of Rains, seven different lava flows were discovered. The relative age of these formations was determined from their mutual superpositions. A comparison of the relative time of appearance and coloration has shown that the lower, older flows exhibit a tendency toward a greater reddening. According to the

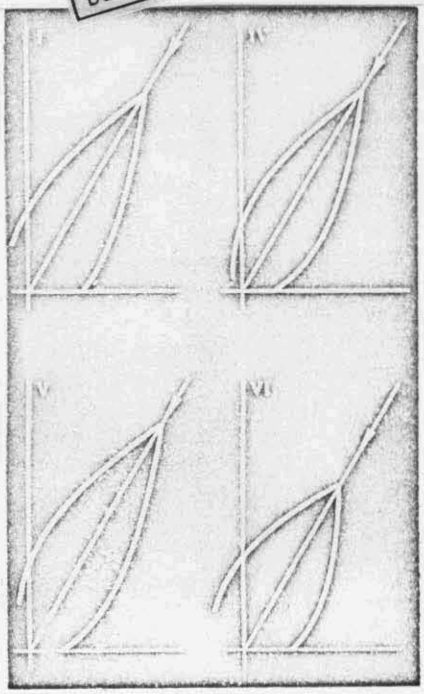

Figure 5.
Scattering indices describing the reflectivity of surface regions, and belonging to various types of photometric relief. The plot shows what fraction of the incident light (in % %) is reflected in various directions by the lunar surface. The vertical axis is the normal to the surface; the arrow indicates the direction of incidence of the solar rays. The curves with various extensions toward the light source correspond to various types of photometric relief.

endogenic concept of relief formation, the older formations should exhibit a greater degree of reddening due to "chemical erosion" (according to A.V. Khabakov). Portions of maria with this type of tendency are also characterized by a higher albedo, which also indicates that the crust in those regions was formed relatively early.

The degree of the restructuring of the maria surface by external factors can serve as a measure of the absolute age formations. In particular, a criterion of this type is provided by the number of craters of meteoric origin. Studies of the distribution of the meteorite matter in the vicinity of the Earth and the Moon permit us to calculate the frequency with which meteorites of various mass fall on the lunar surface. On the other hand, the known velocity and mass of a meteorite make it possible to calculate the size of the impact crater formed on the lunar surface. Figure 3 shows the absolute time scale for the development of the Moon, calculated using the above technique. The scale shows the main periods of the lunar history. The Imbrian and Procellarum periods encompass the appearance of the maria. The Eratosthenian and Copernican periods encompass the formation of a majority of the post-maria craters.

The table compares the relative age and coloration of a number of formations in the region of the Sea of Serenity and the Sea of Tranquility. The first characteristic parameter has been taken from selenological maps.

TABLE

| | | |
|---|---|---|
| Arguelles Peak | I | Pre-Imbrium |
| Mountains to the north of the Arguelles Peak | I | Pre-Imbrium |
| Haemus Mountains | I | Imbrian |
| Archeruse Cape | I | Imbrian |
| South of the Menelaus A crater | I | Imbrian |
| Central portion of the Sea of Serenity | II | Procellarum |
| Lava flow alongside the Menelaus A crater | III | Procellarum |
| Periphery of the Sea of Serenity | III | Procellarum |
| To the north of the Menelaus A crater | III | Eratosthenes |
| Region between the Archeruse Cape and the Letronne B crater | IV | Eratosthenes |
| Neighborhood of the Daues crater | IV | Eratosthenes |
| Menelaus A crater | IV | Copernicus |

The second was taken from the color photographs. Degree I corresponds to the greatest reddening. Thus, these data clearly show that it is useful to correlate the age and the coloration of formations.

Our knowledge is least complete when it comes to the role of the exosphere /44 as the surface-determining component of the lunar landscape zone. There is a very low probability of factors whose results would be manifested in a structural change or a change of optical properties. The regions of the local intensification of processes in the exosphere (i.e., places where gases escape, regions in the neighborhood of impact craters, etc.) may be the only exception. However, the effect of the lunar exosphere on the upper soil layers can only be clarified by comprehensive studies. This is exemplified by the difficulties encountered when determining the absolute age of lunar rocks using the calcium-argon method. It may be that part of $^{40}Ar$ in the lunar specimens is not a decay product of calcium but a result of the captures of gases present in the solar wind. This of course introduces an uncertainty in estimating the age of the rocks.

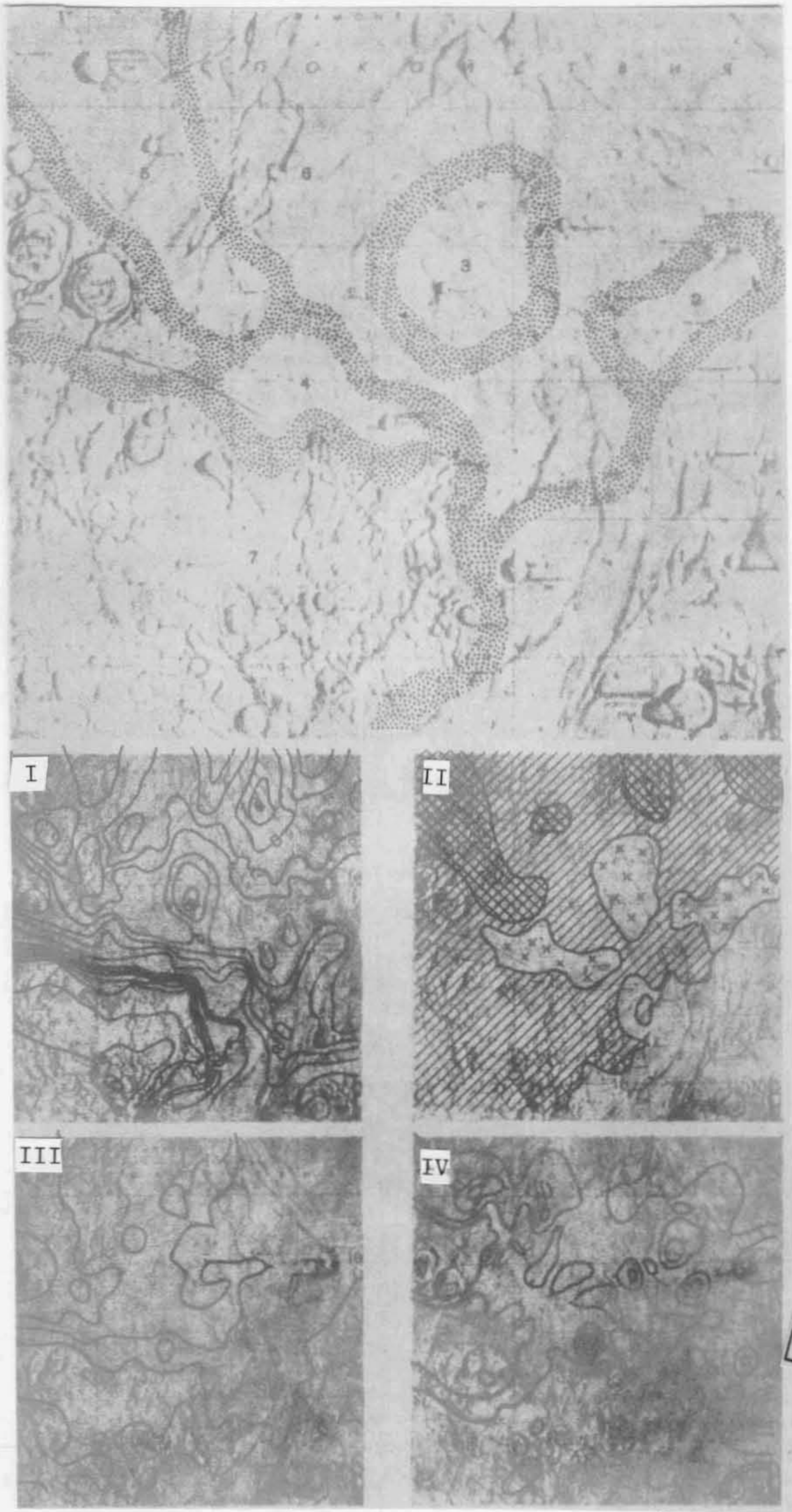


Figure 6. (Caption on following page).

Figure 6.

Map of the physical regions of the southern part of the Sea of Tranquility. The map was prepared on the basis of the following physical maps: I - Map of normal albedo (isophotes near the full moon), II - map of coloration (degree of reddening), III - isoterms near the full moon, IV - isoterms during an eclipse. A surface of the maria type within the region in question can be subdivided into two major segments. In the northern part (segment 6) we have a typical maria region with an average albedo and typical thermal properties. Using the degree of reddening as a criterion, this entire region may be said to have been formed during the Procellarum. In the southern part there is an older region (segment I) which, according to the scale of reddening, was formed during the early period of the formation of maria, i.e., the Imbrian period. This conclusion is confirmed by the slightly elevated albedo which indicates a surface with smaller grains, i.e., a more eroded surface layer. The thermal properties (slower heating of the surface) may be a consequence of the relatively smaller porosity of the soil, its denser packing, which agrees with the conclusion about the fine structure of the upper soil layer. With this kind of structure, the numerous cavities in the lava which has just emerged into a vacuum become destroyed or filled. /43

In addition to this general subdivision, one can point to regions of smaller areas, which have distinguishing characteristics. Segments 2 and 4 are to some extent intermediate in their properties between the types of maria landscape represented by segments 1 and 6. Their location is in full agreement with this type of characterization.

A combined analysis of the properties of segment 5 indicates that it is one of the youngest in the region under consideration. This is shown by the low albedo of the surface. The degree of reddening places it in the Eratosthenes period. The number of post-maria craters within the region is much smaller than in the adjoining region. The low degree of destruction of the porous structure of the crust is also indicated by thermal characteristics such as the rapid heating of the surface, i.e., low thermal conductivity which is characteristic of a porous substance. It may also be that the genesis of this relatively late formation is somehow related to the crack Ritter I which passes through the middle portion of the region.

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## PHYSICAL CARTOGRAPHY OF THE MOON[4]

The existence of the atmosphere and hydrosphere on the Earth in certain cases makes it necessary to take into account the three-dimensionality of the terrestrial landscape zone (one must take into account the thickness of the atmosphere and the depth of the hydrosphere). The lunar landscape zone, considering its peculiarities, may be considered two-dimensional without any approximation. This distinguishing feature of the landscape zone on the Moon means that the creation of physical maps is an efficient method of collection and investigation of information on the properties of the lunar environment.

Physical cartography of the Moon can be defined as a process of constructing cartographical images of the lunar surface containing the information about the presence and distribution of various physical characteristics of the lunar crust.

The process of map-making involves an analysis of a region according to different criteria: morphological and selenological features, optical characteristics, thermal properties, etc. A generalization of the data obtained is the essence of a typological regionalization of a surface. The difference between two regions reduces to the difference between the sets of characteristics corresponding to the regions in question. Thus, types of regions are distinguished on the basis of comprehensive indirect (astrophysical) characteristics.

The next problem involves determining the content of each specific type. This is done in laboratory and field studies of the analogs of the lunar crust. These studies establish a relationship between the astrophysical properties of the surface and the structure, density, heat conductivity, and other parameters of the soil. A comprehensive investigation of similar relationships can also

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(4) For more details, see Yu. N. Lipskiy, V. V. Shevchenko. Fundamentals of the Physical Cartography of the Moon, "Astrononmicheskiy Zhurnal", Vol. 47, 1970, No. 3.

be done by directly studying the chemical composition, physical and mechanical properties of the lunar crust with the help of spacecraft. The individual regionalization[5] of the surface is achieved by systematizing the data obtained in such studies.

The regionalization of the surface permits economical planning of the most difficult research phase — launching spacecraft that are to land on the lunar surface. Since comprehensive physical cartography reliably establishes borderlines between regions with homogeneous characteristics, we are fully justified in extrapolating the parameters obtained at one point (the landing site of a spacecraft) to the entire area of this type. It is possible, on the basis of typological regionalization, that a small number of landings will enable us to investigate large areas on the Moon. The high state of technology involved in the automatic return of lunar probes back to the Earth, indicated by the recent flight of Luna 16, opens up great possibilities in this area.

Generally, the lunar surface can be subdivided according to the character of the relief and the reflectivity of the crust in maria and continents. The continents cover a large fraction of the two lunar hemispheres. Maria represent local impregnations that cover 16% of the total surface of the Moon. The asymmetric location of maria, concentrated on the near side of the Moon, is extremely interesting. An explanation of this phenomenon (whether it is accidental or conforms to a law) may shed some light on certain periods of the Moon's history. The solution of this problem will be made easier when the internal composition of the Moon and the motion of matter in its interior are studied, as well as the properties of the external crust of the Moon, which still possibly may bear the traces of these processes.

The continent landscape of the Moon is highly homogeneous in its physical characteristics. Changes in the albedo over large areas (excluding individual

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[5] The terms "typological and individual regionalization" have been adapted from the earth sciences but the definitions of the operations involved are here somewhat different, as seen from the above description.

craters) are insignificant. According to color photographs, color contrasts are also very rarely observed. For this reason, the physical cartography of the continents will be discussed on the basis of the photometric properties studied in integral (white) light. These properties are determined by two basic characteristics: the albedo and the photometric function, i.e., variation in brightness under various conditions of illumination and observation.

The mathematical form of the law of reflection for the lunar surface, that would fully reproduce all the peculiarities of the way light is reflected by the Moon, has not yet been found. However, there are approximate formulas. Among them is a formula, derived by the American astronomer B. Hapke, that enjoys a great popularity, and rightly so. The parameters of the photometric function in this formula include characteristics such as the "packing factor" (degree of relative density of the upper soil layer), fraction of the surface occupied by irregularities, and the average angle of inclination of the relief forms.

If one takes into account a certain number of brightness measurements of the same region under various conditions of illumination and observation, then the parameters in the formula may be thought of as unknowns, and their values can be obtained by solving the system of equations in question. Fig. 4 shows a photometric map, constructed according to the above method, of a portion of the continent landscape on the far side of the Moon. Brightness data were obtained from the photographs taken by the "Zond-3" lunar probe in 1965. By combining various values of the photometric function parameters, we can obtain six types of "photometric relief" of a locale, which permits us to perform a typological regionalization of the area. The difference between the photometric properties of various regions is illustrated by the plots in Fig. 5, which refer to some of the types of the "photometric relief". /45

An even fuller characterization of a locale can be obtained on the basis of physical cartography including an analysis of a greater number of the physical properties of the lunar crust. This process will be discussed using the example of physical cartography for a region of maria landscape — namely, the southern part of the Sea of Tranquility (Fig. 6).

Segment 4, which contains (taking into account the washed-out boundaries between regions) the landing site of Apollo 11, is of particular interest. As we know, the average age of the lunar rocks, as determined from an analysis of the samples collected at that site, was about 3.7 billion years. According to the scale of "reddening", segment 4 as a whole, and the landing site in particular, can be classified as belonging to the initial stage of the Procellarum period. According to the lunar time scale (see Fig. 3), in absolute terms this means about 3.9-3.8 billion years. Taking into account the fact that the problems involved in the absolute determination of the age of lunar regions by astronomical methods have not been sufficiently studied, the agreement must be considered as good.

The latest successes of space science and technology give us a more concrete idea of the possible relationships between terrestrial observations and those done directly on the Moon.

An excellent example is the work of the automatic space vehicle "Lunokhod - 1" which was placed on the Moon on November 17, 1970 by Luna-17.

The equipment on board the first mobile laboratory made a comprehensive investigation of a number of characteristics of the lunar crust. An X-ray spectrometer was used to determine the chemical composition of the upper soil layer. Penetration of the soil by a special digger and monitoring by a system of force measuring devices on the undercarriage of Lunokhod supplied information about the mechanical properties of the surface. The television images of the surrounding landscape transmitted back to the Earth made it possible to obtain data on the structure and certain optical properties of the soil.

These extensive exploration capabilities have been amplified many times by the ability of the device to move around. Already during the first few days of operation, Lunokhod-1 covered a significant distance. On November 18, during a session lasting 4 hours 40 minutes, the vehicle covered a distance of 96 m. On November 20 during a session of similar length, the Lunokhod traversed a distance of 82 m.

Thus, in our discussion of the future prospects for physical cartography, we must include the fact that on the lunar surface it will be possible to plan routes along which a number of the parameters of the lunar environment will be determined. What is most important is that such routes can cross boundaries of regions delimited in the typological regionalization. Consequently, it will be possible to study the causes of the diverse nature of various lunar regions.

These examples of physical cartography and interpretation of the information supplied by it are of course still far from a final interpretation of the nature of the regions in question. This will take place only after more detailed and comprehensive studies. However, the above results of the stage-by-stage regionalization of the selected areas on the Moon point with sufficient eloquence to the effectiveness of the method used. It is difficult to say what the precise form of such studies will take in the future, but apparently there has been a qualitative transition to a comprehensive investigation of the distribution of the lunar landscape characteristics over large areas of the lunar surface.

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